Holocene Eruptive Activity Recorded as Volcanic Glass in the Sediments of Beppu Bay, Central Kyushu, Japan

AUTHOR(S):

Takemura, Keiji

CITATION:

Takemura, Keiji. Holocene Eruptive Activity Recorded as Volcanic Glass in the Sediments of Beppu Bay, Central Kyushu, Japan. Memoirs of the Faculty of Science, Kyoto University. Series of geology and mineralogy 1995, 57(2): 1-10

ISSUE DATE:

1995-10-31

URL:

http://hdl.handle.net/2433/186677

MEMOIRS OF THE FACULTY OF SCIENCE, KYOTO UNIVERSITY, SERIES OF GEOL. & MINERAL.,
Vol. LVII, No. 2, pp. 1-10, 1995

Holocene Eruptive Activity Recorded as Volcanic Glass in the Sediments of Beppu Bay, Central Kyushu, Japan

By

Keiji TAKEMURA*

(Manuscript received March 30, 1993)

Abstract

The eruptive history around Beppu Bay, central Kyushu, Japan, is investigated using a 15 m-long sedimentary core obtained with a piston corer. A standard method to determine the down-hole content of volcanic glass was used in this study. This method consists of two steps: (1) systematic separation of the volcanic glass particles from samples taken at close intervals, and the determination of their relative concentration; (2) precise measurement of the refractive indices of the separated glass particles. A recently developed measuring system (RIMS 86) based on the thermal immersion method permitted quick and accurate measurement of the refractive index of a large number of samples.

Five discrete tephras erupted since 7,500 y B.P. occur within the sedimentary succession underlying Beppu Bay. The oldest tephra is correlated with the widespread K-Ah tephra originating from the Kikai Caldera is southern Kyushu Island. The other four tephras (ca. 5,000 y B.P., 4,000 y B.P., 2,000 y B.P. and 1,500 y B.P.) are considered to represent eruptives of more proximal volcanoes located in the area surrounding Beppu Bay.

I. Introduction

In profiles of subaerial and marine sequences it is difficult to verify the original stratigraphic position of thin superimposed or disseminated tephra because of syn- and post-depositional reworking and mixing processes. The original stratigraphic position of the dispersed tephra in such sections is usually established from the level of maximum concentration of glass shards as determined by laboratory analysis of the host sediments (RUDDIMAN & GLOVER, 1972; HUANG et al., 1973 etc). To estimate the original position and hence age of the dispersed tephra, it is important that closely spaced samples are obtained from core sections that are as complete as possible, and that analysis are undertaken that tephra of different age and origin can be discriminated.

TAKEMURA and DANHARA (1988) described a routine method to determine types of concentration in volcanic glass by measuring the refractive index using a thermal immersion method. The purpose of this paper is to determine the record of Holocene eruptive activity in central Kyushu, Japan with this method by application of it to a 15 m-long

*Department of Geophysics, Faculty of Science, Kyoto University, Kyoto, 606-01 Japan

core in Beppu Bay.

The Beppu district is situated in northeastern Kyushu Island, Japan (Fig. 1). Mt. Tsurumi-dake and Mt. Yufu-dake are located in this district. The late Pleistocene eruptive history of these volcanoes has been described by KOBAYASHI (1984) and HOSHIZUMI et al. (1988). They identified one eruption including formation of a lava flow at about 2,000 y B.P. Holocene eruptions of smaller magnitude probably occurred but cannot be discriminated in near source areas. If such events have occurred, they should be recorded in the sedimentary succession in Beppu Bay, situated about 10 km east of the active volcanoes and their identification in these sediments would enable the volcanic history of the Tsurumi-Yufu Volcanic Group to be reconstructed.

II. Method to Determine Concentration of Volcanic Glass in Sedimentary Sequences

This method reveals the concentration types of various volcanic glass particles with different refractive indices, which makes it possible to recognize certain tephra-horizons, even those undetectable through visual observation of sedimentary columns. Tephras so detected can be correlated with known tephras using a combination of their refractive index and grain morphology. The degree of dissemination of the glass shards gives information about the syn-depositional or post-depositional reworking of tephra layers.

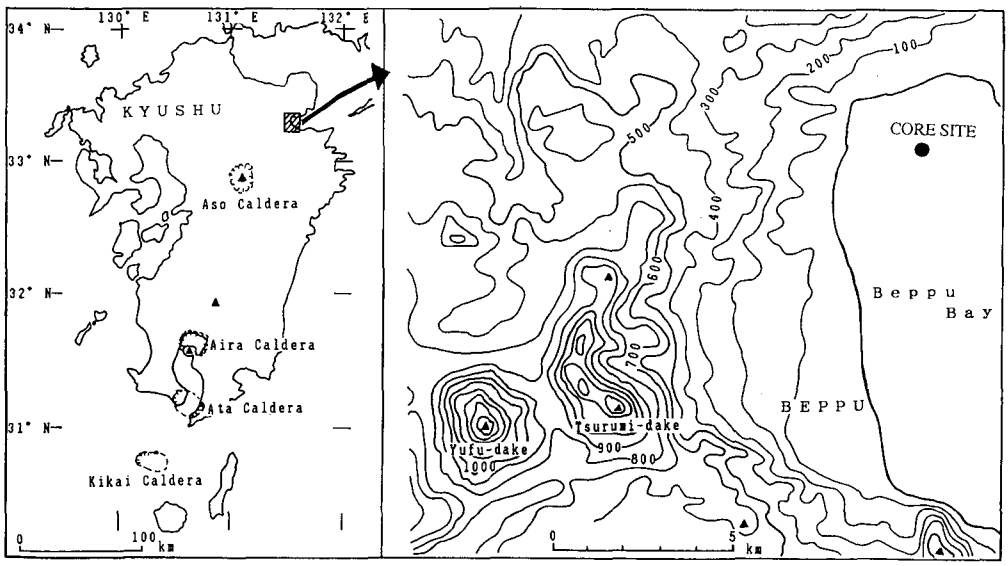

Fig. 1. Topographic map of Beppu Bay area and core location, with location of large Late Quaternary calderas in Kyushu.

The type of tephra dispersion can be determined using the following procedure:

First Phase:

1. Sampling of a continuous sedimentary sequence and description of its lithology.
2. Down-hole or section sampling at 5 – 10 cm intervals.
3. Wet-sieving (60, 120, 250 meshes) followed by drying and weighing of each size fraction, followed by determination of the grain size distribution.
4. Preparation of thin sections of the very fine sand fraction.
5. Modal analysis of the very fine sand fraction including counting of volcanic glass, heavy minerals, light minerals and other grains. Normally 200 grains are counted.

Second Phase:

6. Refractive index measurement of volcanic glass grains. The refractive indices of volcanic glasses are measured using the thermal immersion method described by YOKOYAMA et al. (1986). Immersion oil is a mixture of difroil and alpha-chloronaphtalene. In this study, immersion oils named No.3.5, No.4.0, No.4.5 and No.5.5 were used. Measurements on standard glasses (artificial glasses) indicated that the relationship between refractive index and temperature of each immersion oil is linear. Indices of at least 30 grains in each sample are measured.
7. Data presentation by histogram.
8. Classification of the type of tephra dispersion using the scheme documented by TAKEMURA and DANHARA (1988) (Fig. 2). These types are listed as follows:

Type a1: Mesoscopic tephra layer with discrete upper and lower boundaries.

Type a2: Mesoscopic tephra layer with a diffuse upper boundary, giving a skewed distribution of glass content with stratigraphic position.

Type b: Microscopic tephra layer with a diffuse upper boundary and skewed distribution as above.

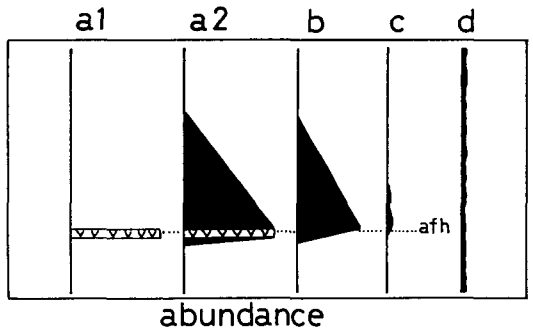

Fig. 2. Types of glass concentration pattern in sedimentary sequences (TAKEMURA and DANHARA, 1988). *afh: ash fall horizon.*

Type c: Microscopic tephra layer with a small amount of volcanic glass recognizable in a narrow horizon. Airfall deposition still inferred.
Type d: Fully dispersed microscopic tephra layer including deposition from sedimentary processes only.

III. Descriptions of The Samples

The samples analyzed in this study were obtained by piston corer. The core was obtained from a water depth of 20 m, in the northwestern part of Beppu Bay (Fig. 1). The core site is known as Beppu-88-U (OKAMURA et al., 1992). The core measured 1,454 cm in length and the succession sampled is composed mainly of clay to sandy clay with shell and plant fragments. The core sample was divided into 15 parts of about equal length (labelled U1 – U15 in ascending order) and then subdivided into 10 cm-thick intervals. As the upper samples of some of the 15 parts are less than 10 cm long, the total number of samples examined is 148. Grain size analysis was carried out on all 148 samples. Grain composition analysis using the fraction of very fine sand (63 – 125 micron) and refractive index measurement were carried out for about every other samples (total 72).

IV. Result

Analytical results are shown in Fig. 3. Each 10 cm thick interval is numbered with the bottom depth in cm. Fig. 3 shows the vertical distributions of sand content, grain composition (volcanic glass, heavy minerals, light minerals, diatoms and other bioclasts) of the very fine sand size fraction (63 – 125 microns), and histogram of refractive index of volcanic glass. Results will be discussed in the stratigraphic order of the samples.

The sand content from bottom sample (1,454 cm depth) to the sample of 1374 cm depth is less than 1%. All the very fine sand sized grains (63 – 125 micron) are composed of volcanic glass, light minerals, diatom fossils and other bioclasts such as shell fragments. The shards are made of transparent bubble walls, and they have two groups of refractive index values of 1.498 – 1.501, and 1.508 – 1.512 (which are hereafter abbreviated as R.I.=1.498 – 1.501, 1.508 – 1.512). Volcanic glass particles of R.I.=1.498 – 1.501 are observed up to 1,313 cm depth, and appear again from 1,146 cm depth to the top of the core.

At 1,273 cm deep, the sand content reaches 12 percent. The distribution of the sand content in adjacent sediment layers shows an asymmetric and decreasing upwards pattern. This horizon is correlated with the reflection horizon detected during the seismic survey (SHIMAZAKI et al., 1986), which are continuous throughout most of Beppu Bay. An acme of concentration in volcanic glass, with an asymmetric depth distribution, is

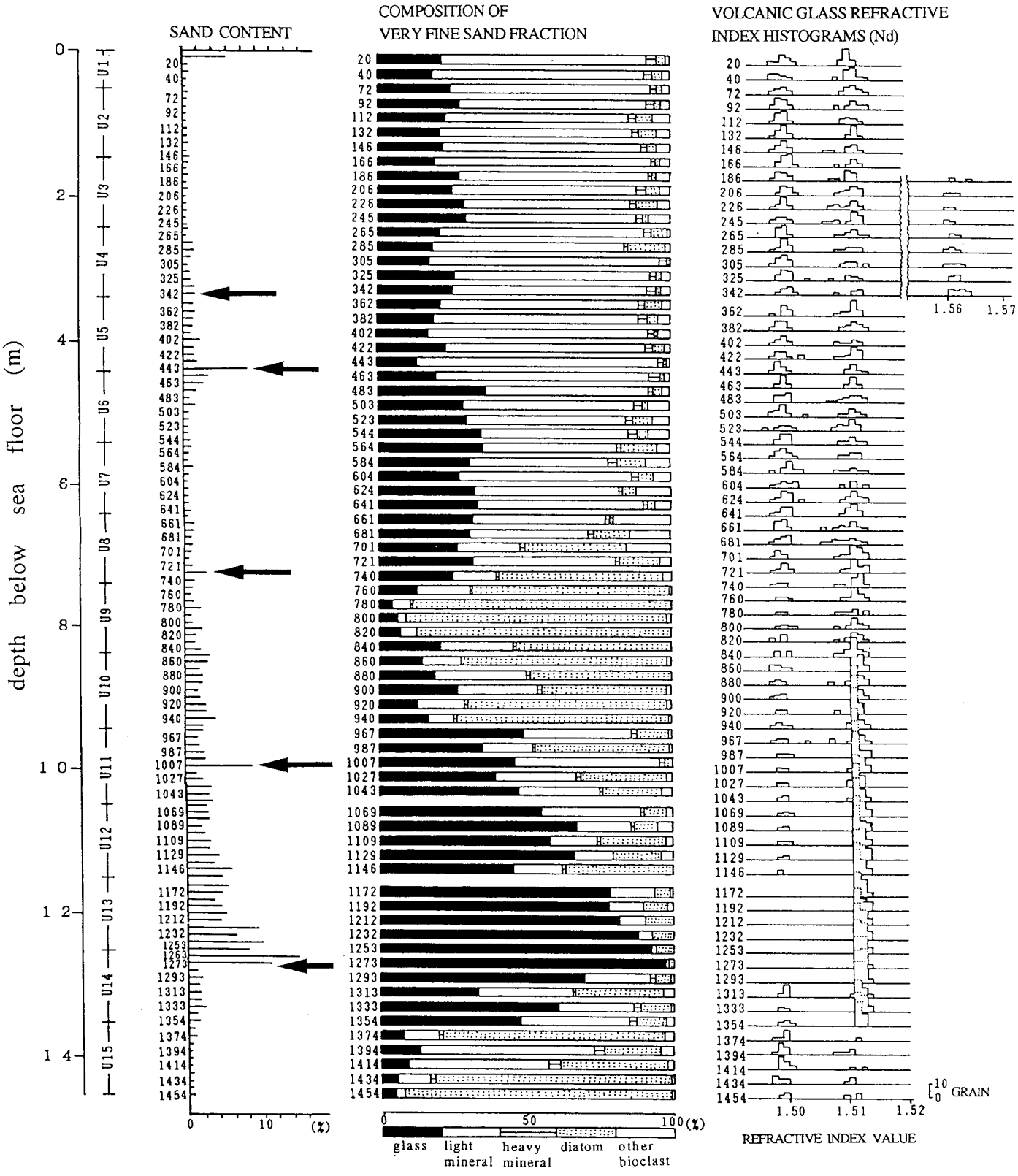

Fig. 3. Results of the analysis of samples from Beppu Bay core (Beppu-88-U) including sand content, grain composition and refractive indices of volcanic glass. Contents of grains coarser than 63 micron are shown in weight percentage. Column of grain composition represents the percentage of counts of volcanic glass, light minerals, heavy minerals, diatoms and other bioclasts. Grain composition was checked for the fraction of 63–125 micron. The horizontal axis of refractive index histogram represents the value of refractive index, and the vertical axis indicates frequency of glass shards. Arrows show tephra horizons identified.

also present at 1,273 cm sub-bottom depth synchronous with the horizon of highest sand content. The proportion of the glass of R.I.=1.510–1.513 increases from 1,354 cm to 1273 cm depth, and the glass of this type occupies most of the glass shards between 1,293 cm and 1,172 cm depth, and contributes up to the top of core. Brown colored glass shards are observed at these horizons, and the proportion of the brown glass is 2–3% of the total amount of glass. Small amounts of bubble wall type glasses with R.I.=1.498–1.501 are also observed from 1,146 to 1,027 cm depth in the core.

The sand content increases abruptly to 8% at 1,007 cm deep, from less than 3% of adjacent sediment samples. This horizon is also correlated with a continuous sub-bottom reflection horizon detected during the seismic survey (SHIMAZAKI et al., 1986), and continuous throughout most of Beppu Bay. The light mineral content increases and diatom fossils become very rare at this horizon. Light minerals with glassy selvedges are also observed. Pumice type glass with R.I.=1.498–1.502 increases at 1,007 cm depth. The contribution of the glass of this type continues to the 967 cm depth.

A small peak in sand content occurs at 731 cm. The sand is composed mainly of light minerals, volcanic glass shards and diatom shells. Light minerals with glassy selvedges are also evident. The upper part of the sediment core, from depth of 721 cm to the surface, generally has a low content of diatom fossils and a high content of minerals and glasses. The proportion of pumiceous glass shards with R.I.=1.497–1.502 increases again at 721 cm, but decreases upwards.

Another 8% peak of sand content occurs at 443 cm. The sand is composed mainly of light minerals, volcanic glass shards and diatom fossils. Light minerals with glassy selvedges are also observed. This horizon is also correlated with a reflection surface mapped during the seismic survey (SHIMIZAKI et al., 1986), which is continuous throughout most of Beppu Bay. Volcanic glass of R.I.=1.497–1.502 at 443 cm are mostly composed of pumice type glass shards, and the amount of the glass of this type decreases upwards.

Pumice type glasses of distinctive greenish brown color are observed at 342 cm, the glass having R.I.=1.559–1.564. It represents about 20% of total glass shards, and the ratio decreases upwards.

V. Discussion

〈Origin of volcanic glass and volcanic ash horizons〉

Volcanic glass shards reworked from tephra erupted before the deposition of the sequence analyzed are contained in the sedimentary sequence as dispersed terrigenous grains. This type of dispersion is referable to the type d concentration of TAKEMURA and DANHARA (1988). One of the source tephra of this background glass is the Aira-Tn (AT) volcanic ash (MACHIDA and ARAI, 1976) which erupted from the Aira Caldera situated in

the southern part of Kyushu Island at about 25,000 y B.P. (MATSUMOTO et al., 1985). The volcanic glass shards originating from AT ash are mainly composed of transparent bubble wall type shards and have a R.I.=1.499–1.501. In southwest Japan, the volcanic glasses of AT ash are commonly observed even in soil sequences (TAKEMURA and DANHARA, 1988). In the sedimentary core of Beppu Bay, volcanic glass shards of R.I.=1.498–1.501, contained below the sample at 1,313 cm depth, originated from AT ash. They are absent in the section between 1,313 cm to 1,146 cm, and the volcanic glass particles reworked from AT ash are also observed in the core above 1,146 cm. Volcanic glass shards of R.I.=1.508–1.512 below the 1,354 cm horizon may have been the reworked from still older volcanic eruptives.

Excluding the reworked glass shards, the following five episodes recording past volcanic activity can be recognized in the core from Beppu Bay. They are described in ascending order.

1. 〈ca.1,273 cm in depth〉 This is a clear tephra horizon indicated by the high concentration of volcanic glass (Fig. 3), which is of bubble wall type with R.I.=1.510–1.512. This unit shows the characteristics of type b tephra (TAKEMURA and DANHARA, 1988). Small amounts of brown glass are present. Volcanic glass shards of this tephra are present throughout the core above 1,354 cm. This tephra horizon is associated with a seismic reflection horizon, which is continuous throughout most of Beppu Bay. In the predominantly homogeneous clay-silt sequence, this reflection horizon originates from the coarser sediment texture associated with the tephra. The logic may also be reversed: continuous reflection horizons in this type of setting are probably due to marine-fall tephras.

2. 〈ca.1,007 cm in depth〉 This horizon is indicated by the occurrence of glassy selvedges on light minerals and by pumice glass shards with a R.I.=1.498–1.502. (Fig. 3). This horizon is also correlated with a reflection horizon and abrupt appearance in the sequence of sand grains. Sediments below and above this horizon are composed of homogeneous clay-silt. The thin continuous occurrence of this horizon is consistent with its origin as a tephra horizon.

3. 〈731–721 cm in depth〉 This tephra is characterized by the occurrence of light minerals with glassy selvedges and pumice type glass shards with R.I.=1.497–1.502.

4. 〈ca.443 cm in depth〉 This tephra is determined from the occurrence of light minerals with glassy selvedges and pumice type glass shards with R.I.=1.497–1.502. This horizon is also correlated with reflection horizon and abrupt increase of sand grains. Sediments below and above this horizon are composed of homogeneous clay-silt. These facts support that this is tephra horizon.

5. 〈ca.342 cm in depth〉 This tephra is characterized by the existence of greenish brown colored volcanic glass shards of high R.I.=1.559–1.564.

The concentration patterns of ca. 1,007 cm, ca. 731–721 cm, ca. 443 cm and ca. 342

cm horizons are type c dispersed tephra of TAKEMURA and DANHARA (1988).

〈Chronology and volcanic history around Beppu Bay〉

The tephra occurring at ca. 1,273 cm horizon is correlated with the widespread K-Ah (Akahoya) volcanic ash (MACHIDA & ARAI, 1978), which erupted from the Kikai Caldera situated to the south of Kyushu Island at 6,300 y B.P. on the basis of glass type and refractive index values. K-Ah ash is widely distributed in onshore areas surrounding Beppu Bay, where the thickness of the ash bed exceeds 20 cm. The age of this tephra essentially provides the chronology of the core.

Tephra at ca. 1,007, ca. 731 – 721 cm, and ca. 443 cm are similar in their glass type and refractive index values. This suggests that the tephras were derived from the same eruptive source. Their characteristics are similar to the Yufu-dake Ash erupted from Yufu-dake volcano at 2,000 y B.P. (KOBAYASHI, 1984). This ash has a thickness of about 5 – 20 cm on land around Beppu Bay. It is reasonable to suggest that the tephra at 443 cm horizon is correlated with Yufu-dake Ash taking into account the thickness and the distinct seismic reflection horizon in the bay (OKAMURA et al, 1992). The age of thin tephra in the core (1,007 cm horizon) is estimated to be about 5,000 y B.P., assuming a constant sedimentation rate and interpolating between the age of the 1,273 cm horizon (6,300 y B.P.) and the age of the 443 cm horizon (ca. 2,000 y B.P.). In the same way, the age of the 731 – 721 cm horizon and the 342 cm is about 4,000 y B.P. and 1,500 y B.P. respectively.

The history of volcanic activity recorded in a 15 m core sample in Beppu Bay is summarized as follows. The bottom age of the core sample is estimated to be 7,500 y B.P., assuming a constant sedimentation rate and extrapolating between the age of the 1,273 cm horizon and the age of the 443 cm horizon. The first volcanic event was the ash fall of the K-Ah ash, originated from southern Kyushu at 6,300 y B.P. The tephra is at least 20 cm thick around the Beppu area. Subsequent volcanic events occurred at about 5,000 y B.P. and 4,000 y B.P. near Beppu Bay. At about 2,000 y B.P., Yufu-dake summit lava erupted accompanied with Yufu-dake volcanic ash fall, and this ash fall fell in and around Beppu Bay. The last volcanic episode recorded in the core has an age of about 1,500 y B.P.

VI. Concluding Remarks

Five discrete volcanic episodes are recognized within the sediments in Beppu Bay since ca. 7,500 y B.P. on the basis of volcanic glass analysis (concentration of glass particles, glass morphology, refractive index). One is the widespread K-Ah volcanic ash, and the other four tephras represent eruptives of volcanoes in the area surronding Beppu Bay. These results have significance for reconstructing of eruptive history and predicting volcanic activity of the Mt. Tsurumi-dake and Mt. Yufu-dake Volcanic Group. Even smaller

events might be recorded in lakes and bogs nearer the active volcanoes. The method applied here may prove to be useful for establishing precise information about smaller events in the eruptive history of active volcanoes.

Acknowledgements

I appreciate Prof. K. SHIMAZAKI (University of Tokyo) and Prof. M. OKAMURA (Kochi University) for providing the core sample. Mr. T. DANHARA (Kyoto Fission-track Co. Ltd) helped measurement of the refractive index of glass particles using the RIMS86. I would like to express my thanks to Prof. P.A. MEYERS (University of Michigan) for reading an early draft. I would like to thank Prof. K. CHINZEI and Prof. T. SHIKI (Kyoto University) for valuable discussion. This work was supported by the INAMORI Foundation.

References

HOSHIZUMI, H., ONO, K., MIMURA, K. and NODA, T. (1988): Geology of the Beppu district. With Geological Sheet Map at 1:50,000, Geol. Surv. Japan, 131p.

HUANG, T.C., WATKINS, N.D., SHAW, D.M. and KENNET, J.P. (1973): Atmospherically transported volcanic dust in south Pacific deep sea sedimentary cores at distances 3000 km from the eruptive source. Earth and Planetary Science Letters, **20**, 119–124.

KOBAYASHI, T. (1984): Geology of Yufu-Tsurumi volcanoes and their latest eruptions. Mem. Geol. Soc. Japan, **24**, 93–108.

MACHIDA, H. and ARAI, F. (1976): The discovery of the widespread tephra Aira-Tn volcanic ash and its significance. Kagaku, **46**, 339–347.

MACHIDA, H. and ARAI, F. (1978): Akahoya ash-a Holocene widespread tephra erupted from the Kikai Caldera, south Kyushu, Japan. The Quaternary Research (Japan), **17**, 143–163.

MATSUMOTO, E., MAEDA, Y., TAKEMURA, K. and NISHIDA, S. (1985): New radiocarbon age of Aira-Tn (AT). The Quaternary Research (Japan), **26**, 79–83.

OKAMURA, M., SHIMAZAKI, K., NAKATA, T., CHIDA, N., MIYATAKE, T., MAEMOKU, H., TSUTSUMI, H., NAKAMURA, T., YAMAGUCHI, C. and OGAWA, M. (1992): Submarine active faults in the northwestern part of Beppu Bay, Japan –On a new technique for submarine active fault survey–. Mem. Geol. Soc. Japan, **40**, 65–74.

RUDDIMAN, W.F. and GLOVER, L.K. (1972): Vertical mixing of ice-rafted volcanic ash in North Atlantic sediments. Geological Society of American Bulletin, **83**, 2817–2836.

SHIMAZAKI, K., NAKATA, T., CHIDA, N., MIYATAKE, T., OKAMURA, M., SHIRAGAMI, H., MAEMOKU, H., MATSUKI, H., TSUJII, M., KIYOKAWA, S., and HIRATA, K. (1986): A preliminary report on the drilling project of submarine active faults beneath Beppu Bay, southwest Japan, for longterm earthquake prediction. Active Fault Research, **2**, 83–88.

TAKEMURA, K. and DANHARA, T. (1988): A standardized method to determine volcanic glass concentration patterns in soil sequence and its application on columnar samples from several archaeological sites. Archaeology and Natural Science, **20**, 35–50.

YOKOYAMA, T., DANHARA, T. and YAMASHITA, T. (1986): A new refractometer for volcanic glass. The Quaternary Research (Japan), **25**, 21–30.